Environmental Studies No. 19

Sump Studies IV: Permafrost Terrain Disturbances Adjacent to Exploratory Wellsites, Northern Yukon Territory

Northern Affairs Program

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Cette publication peut aussi être obtenue en français.

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SUMMARY

During July 1979 geomorphological investigations were undertaken at five abandoned oil and gas wellsites in Eagle Plain and Peel Plateau regions of northern Yukon Territory (NTS 106L, 116I, 116H). The following wellsites were visited: Aquitaine Alder C-33, Chevron SOBC WM N. Parkin D-61, SOBC Blackstone D-77, Mobil Gulf Peel H-71, and Gulf Mobil Caribou N-25. They were selected as being either representative of general conditions in the area or were known to have experienced terrain and waste drilling fluid disposal problems. The major conclusion is that wellsite terrain disturbances are not as obvious as in parts of the Mackenzie Delta and Arctic Islands. This probably reflects the generally lower terrain sensitivity of much of interior Yukon Territory together with the relative rapidity of revegetation in these boreal forest-shrub tundra transition zones.

1. THE ALUR SUMP PROJECT

One of the objectives of the ALUR sump project is to provide environmental and geotechnical information related to the construction, use and subsequent rehabilitation of sumps in different permafrost and terrain situations. A further objective is to assess methods of alternate disposal of waste drilling fluids, particularly direct spillage upon the ground. A long term objective is to evaluate the effectiveness of the Territorial Land Use Regulations as they relate to the drilling of oil and gas wells in permafrost and the disposal of drilling fluids.

Earlier reports in this series describe terrain disturbances adjacent to abandoned wellsites in the Arctic islands and the Mackenzie Delta (French, 1978a), and document geothermal changes associated with sump construction and use at two wellsites, one on Cameron Island in the High Arctic and the other in the Caribou Hills in the Mackenzie Delta (French and Smith, 1980). Two further reports describe biological changes at wellsites in the High Arctic (Smith and James, 1980a) and the Mackenzie Delta (Smith and James, 1980b).

This brief report brings together some Yukon background permafrost terrain information and some wellsite observations and experiences which are otherwise unrecorded or scattered in a variety of notes, reports and files. The small sampling here covers a time period during which operators were gaining experience in working in permafrost conditions, researchers were gaining knowledge on terrain sensitivity, and regulators were learning how to set controls to minimise disturbance.

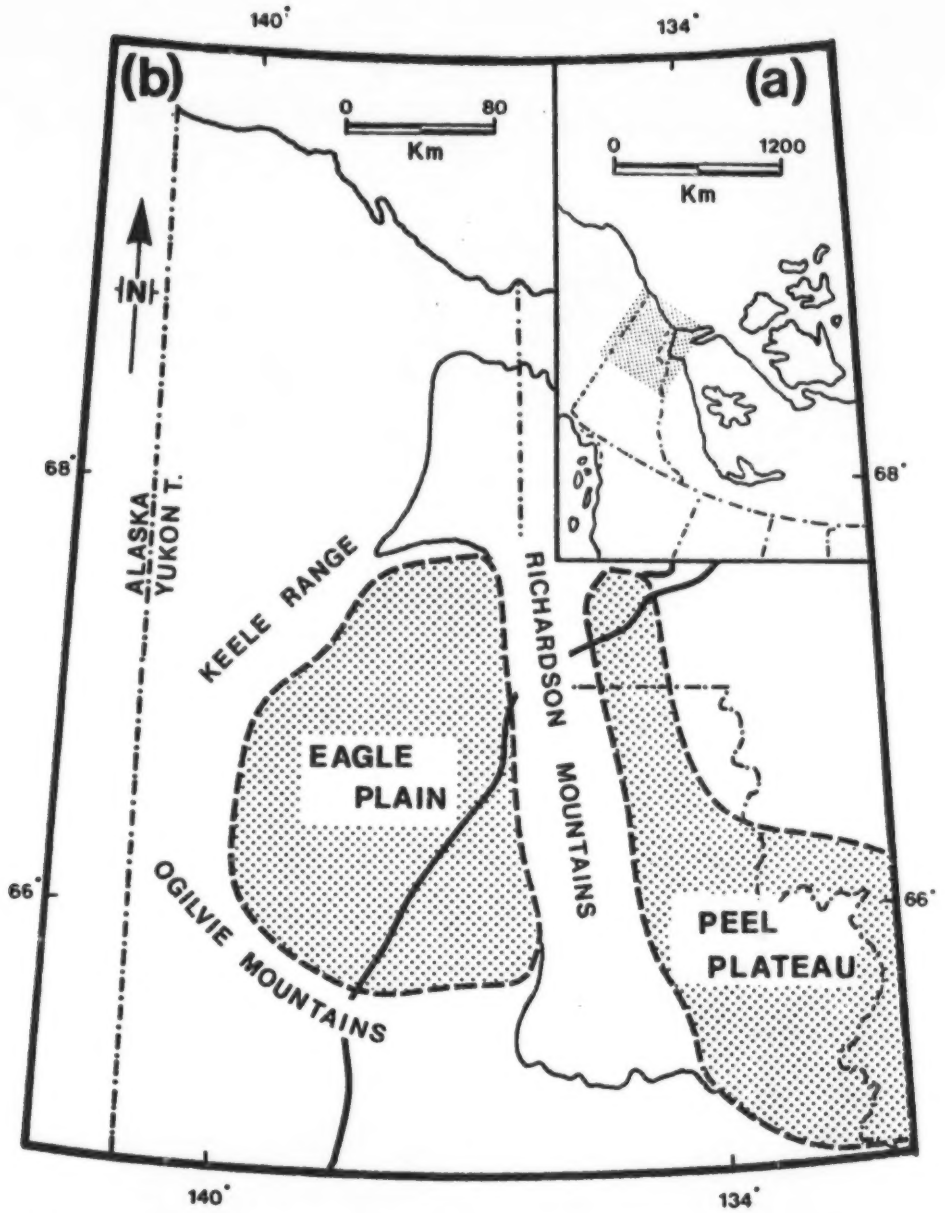
Other papers related to the environmental problems of Canadian Arctic oil and gas exploration include those by Bliss and Peterson (1973) and French (1978b; 1978c; 1980). Similar studies dealing with northern Alaska are also available (Lawson et al., 1978; Lawson and Brown, 1979; Johnson, 1981).

2. PRESENT OBJECTIVES

The report describes physical disturbances adjacent to five abandoned wellsites in the interior northern Yukon Territory. It complements earlier reports which have dealt with wellsite terrain disturbances in the Northwest Territories. Not only are the terrain, vegetation and permafrost conditions different in the northern Yukon Territory from those in the Mackenzie Delta and the Arctic Islands, but also the present observations expand the data base against which the effectiveness of the Territorial Land Use Regulations, as they relate to sumps and the disposal of waste drilling fluids, can be assessed.

Over 50 wells have been drilled in the Yukon Territory. By far the majority are located in either Eagle Plain or Peel River areas of the northern interior (Figure 1). Many of these wells were drilled prior to the introduction of the Territorial Land Use Regulations in 1971.

Following discussions with LAND staff in Whitehorse, a number of wellsites were chosen for detailed field examination. On Eagle Plain these were: Aquitaine Alder C-33, Chevron SOBC WM N. Parkin D-61, and SOBC Blackstone D-77. Two wellsites were examined on Peel Plateau: Mobil Gulf Peel H-71 and Gulf Mobil Caribou N-25. The wellsites are of varying ages and located in a variety of terrain and permafrost conditions. Two (Mobil Gulf Peel H-71, and Gulf Mobil Caribou N-25) were selected specifically on account of known terrain and sump related problems. One (SOBC Blackstone D-77) was selected since it was drilled prior to the introduction of the Territorial Land Use Regulations. The two remaining wellsites (Chevron SOBC WM N. Parkin D-61 and Aquitaine Alder C-33) represent case studies of early and later wells drilled on Eagle Plain subsequent to the introduction of these regulations. At each wellsite an attempt was made to relate the nature and degree of disturbance to the site terrain sensitivity and the history of the drilling operation.



(a) Northern Yukon Territory
(b) Eagle Plain and Peel Plateau

Figure 1. Location map of Eagle Plain and Peel Plateau, northern Yukon Territory. Physiographic regions after Bostock (1971).

3. PERMAFROST AND TERRAIN CONDITIONS

3.1. Terrain

Few studies describe the terrain, permafrost and vegetation conditions of the interior northern Yukon. Even with the opening of the Dempster Highway in 1979, large areas are still inaccessible. Two of the few reports which attempt syntheses of the permafrost and terrain conditions are Zoltai and Pettapiece (1973) and Oswald and Senyk (1977). In addition, maps and reports arising from an Ecological Land Survey (Wilken et al., 1979) are now available (Wilken et al., 1981a; 1981b). These provide a general overview of landscape types in the northern Yukon.

The Eagle Plain constitutes an extensive intermontane plateau lying between 65 and 67 degrees north and covering an area of approximately 17,500 km² (Figure 1). It is bordered on the west and south by the northern and central Ogilvie Mountains respectively, its eastern limit is defined by the southern Richardson Mountains, and its northern limit by the Keele Range. The plateau itself is an upland surface of between 650 and 800 metres in elevation, dissected by broad shallow valleys (Figure 2) which drain northwards to the Old Crow Basin via the Eagle and Porcupine Rivers. The southern edge of the plateau is delineated by a prominent escarpment (Figure 3) formed by a resistant member of the Eagle Plain Formation, a sandstone of Cretaceous age which underlies the majority of the plateau (Norris et al., 1963). Older Carboniferous and Devonian shales, limestones and conglomerates surround Eagle Plain. Vegetation consists of a stunted and open boreal forest which changes to shrub tundra at higher elevations. The alpine tree line decreases northwards in elevation from approximately 850 metres in the south to 600 metres in the north.

The Peel Plateau constitutes an upland surface covering an area of approximately 20,000 km² at the eastern foot of the southern Richardson Mountains (Figure 1). It declines eastwards in elevation from approximately 600 metres to 300 metres. Vegetation is typical of the transition between boreal forest and forest-tundra (Figure 4). Organic material is widespread, particularly in poorly drained areas where peat plateaus, palsas and peat polygons occur (Figure 5). The plateau is underlain by shales and sandstones of Lower Cretaceous age and is dissected by a number of well defined and relatively deeply incised valleys, such as those drained by the Caribou and Trail Rivers. These constitute part of the Mackenzie River drainage system.

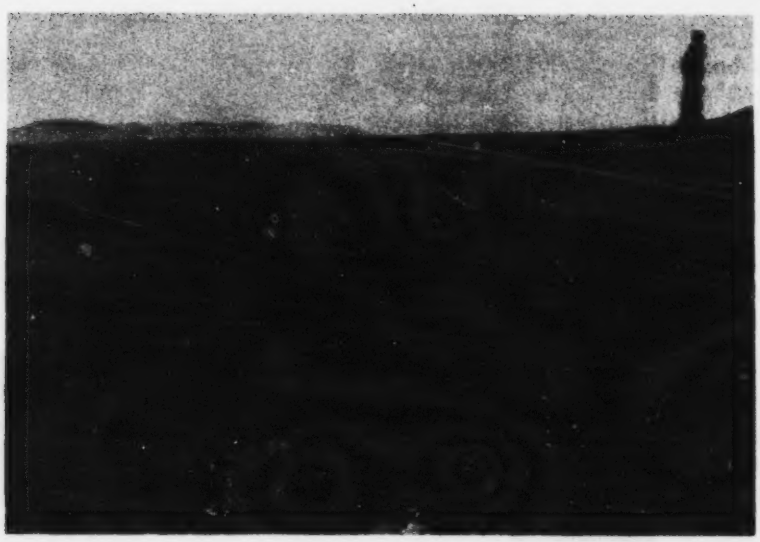


Figure 2. General view of the upland surface of the Eagle Plain. Vegetation consists of an open black spruce woodland and shrub tundra. Lat. 66°16'N, Long. 137°10'W.

Figure 3. View west along the main Eagle Plain escarpment north of the Aquitaine Alder C-33 wellsite. Note shrub tundra on upland surface and assemblage of birch, poplar, alder, and white spruce on warm, well drained southerly exposures. Lat. 65°55'N, Long. 136°50'W.

Figure 4. General view of the Peel Plateau, showing open spruce woodland and tussock hummock tundra. The latter is probably fire-induced. Lat. 66°22'N, Long. 134°52'W.

Figure 5. Area of incipient peat plateaus and wet fenland, Peel Plateau. The surface scuffing relates to a winter airstrip at this locality. Photo taken - July 1979. Lat. 66°20'N, Long. 134°45'W.

3.2. Climate

The present climate of the interior Yukon is cold and continental, the mean annual air temperature at Dawson City (64°04'N; 139°26'W) being -5°C. Further north, at higher elevations in the Ogilvie Mountains and at higher latitudes in Eagle Plain, the mean annual air temperature is probably lower, ranging from -7°C to -10°C (Burns, 1973). Annual precipitation at Dawson City is low, approximately 25 cm, and this is also probably typical of Eagle Plain and Peel Plateau. Unfortunately, no continuous climatological records are yet available for these areas.

3.3. Permafrost conditions

Although mapped by Brown (1978) as transitional from continuous to discontinuous permafrost (Figure 6), very little is known about the permafrost conditions of the northern Yukon. At Dawson City, discontinuous permafrost is known to extend to depths of 60 m (Brown, 1978; EBA Engineering, 1977) while at the Eagle River crossing of the Dempster Highway, borehole data suggest that permafrost may be as much as 90 m thick on the floodplain (Johnston, 1980). At the Eagle River, ground thermal data indicate an active layer exists between May and September and reaches a maximum thickness of almost one metre (Figure 7). Only one well, Socony Mobil WM N. Cath B-62, is logged for temperature in the northern Yukon (Taylor and Judge, 1974). Measurements indicate a permafrost thickness of approximately 100 m, with mean annual ground temperatures of between 0°C and -2°C.

Descriptions of permafrost conditions in the area are vague and reflect this lack of information. For example, it has been suggested that:

(i) 'Permafrost underlies the complete area (Ogilvie Mountains and Eagle Plain), varying from a few hundred feet in depth to possibly over 1,000 feet' (Campbell, 1960, 579).

(ii) '...permafrost occurs throughout the area to depths which locally exceed 400', except beneath well drained south-facing slopes and beneath strips along major streams, where development of permafrost is inhibited by the percolation of groundwater' (Vernon and Hughes, 1966, 4).

(iii) 'Permafrost is essentially continuous in this region except for areas immediately adjacent to major streams and rivers..." (Pufahl *et al.*, 1974, 15).

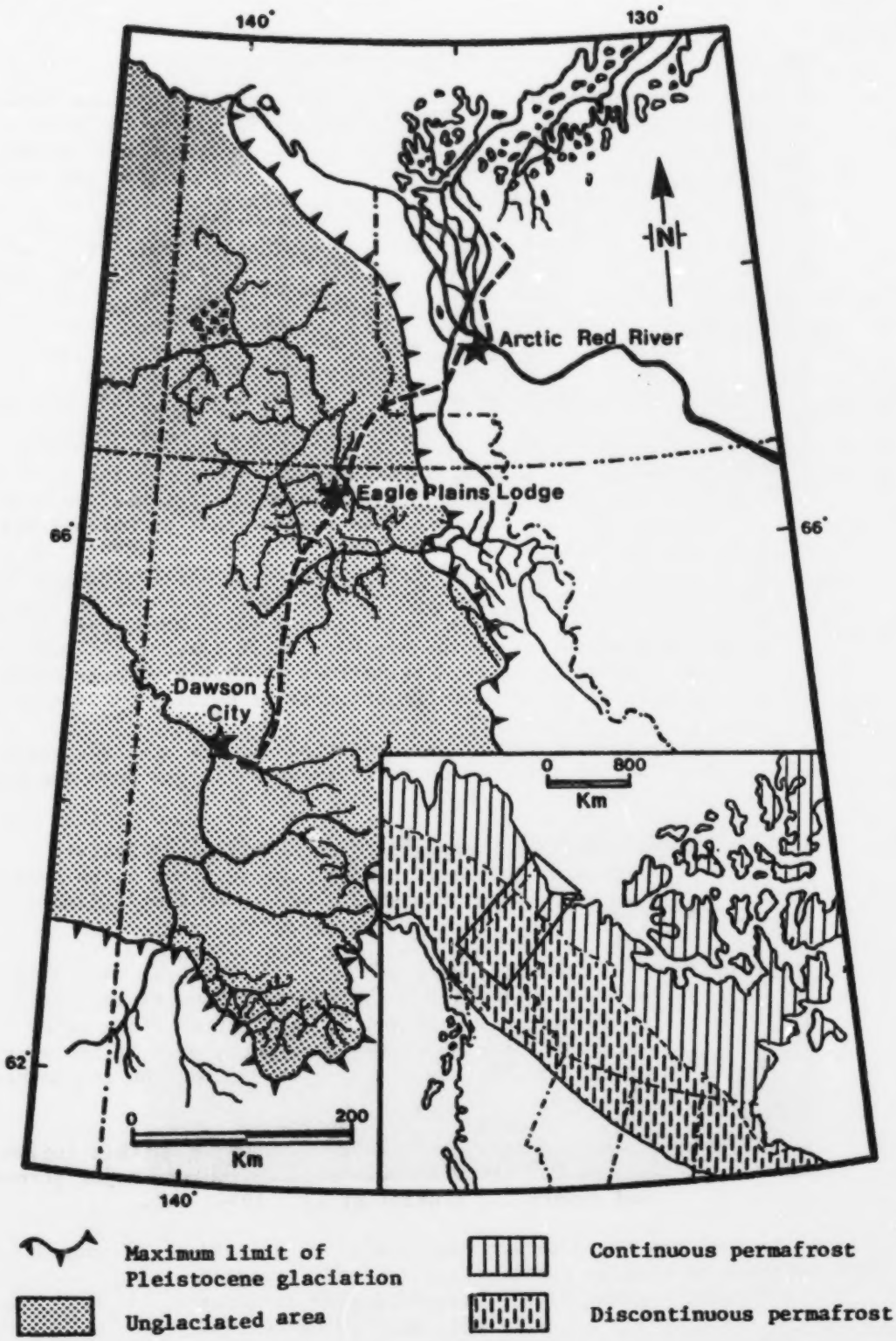


Figure 6. Map showing glacial limits and permafrost zones, northern interior Yukon Territory. After Brown (1978), Hughes (1969) and Hughes et al. (1969).

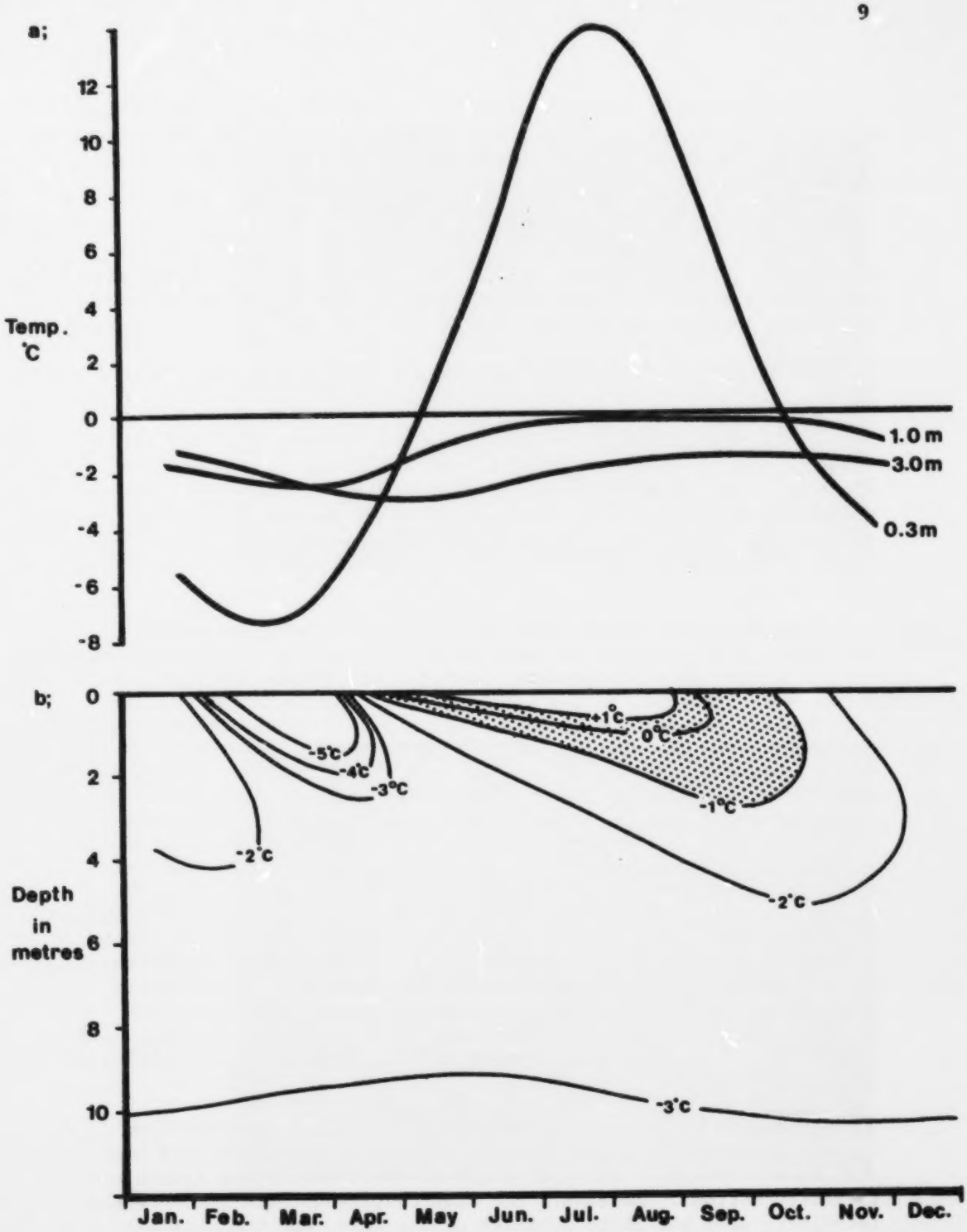


Figure 7. Typical ground thermal regime of fine grained sediments in the Eagle River floodplain adjacent to the Dempster Highway crossing, Eagle Plain. Data supplied by G.H. Johnston, National Research Council of Canada. Stippled area indicates extent of the zero curtain.

The possible presence of relict permafrost is a complicating factor. In the central Yukon, for example at the United Keno Mines, permafrost is known to be at least 450' (137 m) thick (see Brown, 1970, Table 1).

3.4. Surficial geology

The northern Yukon Territory is distinctive in that the majority escaped glaciation by the Laurentide ice sheet. Moreover, the northern and west central portions of the Territory may have remained unglaciated throughout the Pleistocene. The remainder displays a complex pattern of Cordilleran glaciation (Bostock, 1966; Hughes et al., 1969; Vernon and Hughes, 1966).

There is commonly a link between the thickness of permafrost, the presence or absence of ground ice, and the glacial history of an area. Also, glacial events determine, to a large extent, the nature and distribution of surficial deposits which in turn influence soils, vegetation, and terrain sensitivity. This appears true for the northern Yukon (e.g. Zoltai and Pettapiece, 1973; Strang, 1973; Wiken et al., 1981a, 1981b).

Hughes (1969) identified the western limit of Laurentide (Wisconsin) ice as being to the east of the Eagle Plain Plateau where the Richardson Mountains form an imposing topographic barrier (see Figure 6). Likewise, in the south and west, although the Ogilvie and Wernecke Mountains nourished small alpine glaciers, these never extended northwards very far and were confined to the middle and upper reaches of the larger valleys such as the Blackstone. As a result, Eagle Plain experienced a long and uninterrupted period of very intense periglacial conditions. This produced an extensive frost shattered veneer of rock-rubble (felsenmeer) which mantles the interfluves and upper surfaces. Often, this angular regolith has been reworked by frost sorting (Figure 8). Lower valley side slopes are covered with silty colluvium while peaty organic sediments are restricted to depressions. Fluvial deposits, up to 30 m thick, together with ice-rich glacio-lacustrine silts are found along the major river valleys (Hughes, 1969; Johnston, 1980). They suggest that during the late Quaternary period, meltwater streams flowed across Eagle Plain away from the various ice fronts to the east. In places, ponding occurred to produce relatively short-lived proglacial lakes.

Because of the general absence of surficial deposits from large areas of Eagle Plain, unconsolidated, fine grained, and high ice content sediments are restricted to lower valleyside slopes and to valley bottoms. Moreover, the near-continuous forest cover, the relatively poor air photo coverage of the area, and the apparent

Figure 8. Non-sorted circles and stone nets formed in angular bedrock debris near Eagle Plain Lodge, Eagle Plain. Lat. 66°22'N, Long. 136°38'W.

Figure 9. Thermal contraction cracks and peat polygons occur on the floodplain deposits of the Peel River. Note also the area of ribbed fen. Lat. 65°51'N, Long. 136°50'W.

absence of certain terrain features thought diagnostic of highly sensitive terrain in other parts of northern Canada (e.g. pingos, low centred ice wedge polygons, palsas), make the mapping of terrain sensitivity difficult. Within Eagle Plain, however, there are a number of locally important ground ice indicators. These include (a) areas of thermal contraction cracks which form immature polygon nets in valley bottoms where fine grained alluvial and/or colluvial sediments are present (Figure 9), (b) beaded drainage patterns in some of the smaller valleys (Figure 10), and (c) expanded joints in bedrock, commonly exposed in the floors of borrow pits located along the Dempster Highway (Figure 11). The latter are formed by the growth of ice in joints. Similar phenomena occur along the Niagara escarpment in Iowa and Illinois and are interpreted in terms of Pleistocene permafrost (Hedges, 1972).

In contrast to Eagle Plain, Peel Plateau lies within the limits of the Wisconsin (Laurentide) ice sheet. Till and other fine grained sediments occur widely. Zoltai and Pettapiece (1973, 18) report glacial till on the Peel Plateau commonly having in excess of 40% clay content. High ice contents are indicated also by the ubiquitous presence of earth hummocks, areas of tilted and stunted black spruce (Picea mariana), and occasional mudflows and mass movements. The occurrence of massive ice along the eastern slopes of the Richardson Mountains was reported by Zoltai and Pettapiece (1973, 25), although not observed by the present writer. According to Zoltai and Pettapiece, the great majority of massive ice exposures occur in lacustrine deposits. These were formed by temporary pondings of meltwater between the Richardson Mountains and the continental ice sheets. Organic terrain, in the form of peat plateaus, palsas and peat polygon areas, and fenlands, are also important and complicate permafrost distributions. A final terrain consideration is the dissected nature of parts of the Plateau which favour slope instability. In comparison to the unglaciated Eagle Plain, where highly sensitive terrain is restricted mainly to alluvial and lacustrine sediments in valleys, the Peel Plateau possesses generally higher terrain sensitivities.

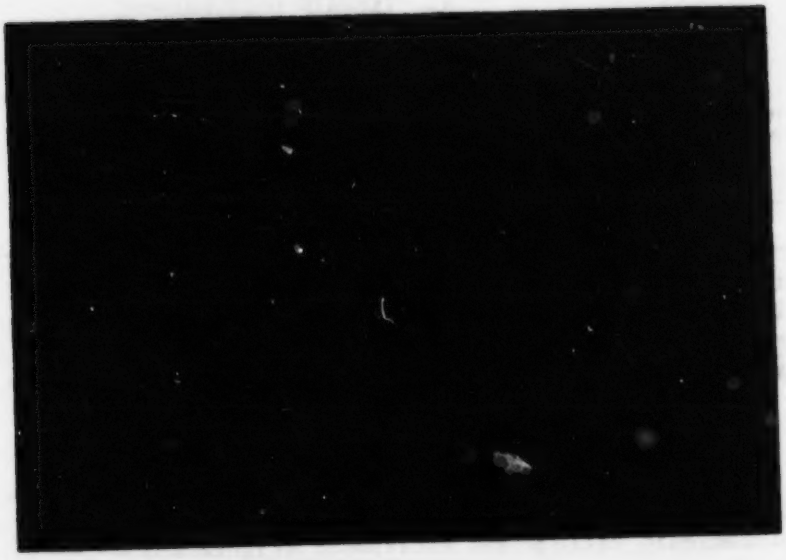


Figure 10. Oblique air view of small tributary stream of Chance Creek which drains part of the southern Eagle Plain. Note the beaded drainage. Lat. 66°15'N, Long. 137°25'W.

Figure 11. Frost-widened joints in shale bedrock exposed in borrow pit at kilometre 366, Dempster Highway, Eagle Plain.

4. TERRAIN DISTURBANCES

Field observations were conducted in July 1979 using a 206 helicopter on contract to Aquitaine of Canada Limited. The Eagle Plain Lodge (kilometre 371, Dempster Highway) was used as a base camp. The locations of the wellsites visited are shown in Figure 12.

A detailed discussion of the Aquitaine Alder C-33 wellsite is presented first. Since site investigations had been undertaken in June 1977 prior to the drilling operation (EBA Engineering Consultants Ltd., 1977; French, 1977), a relatively large data base is available for this wellsite.

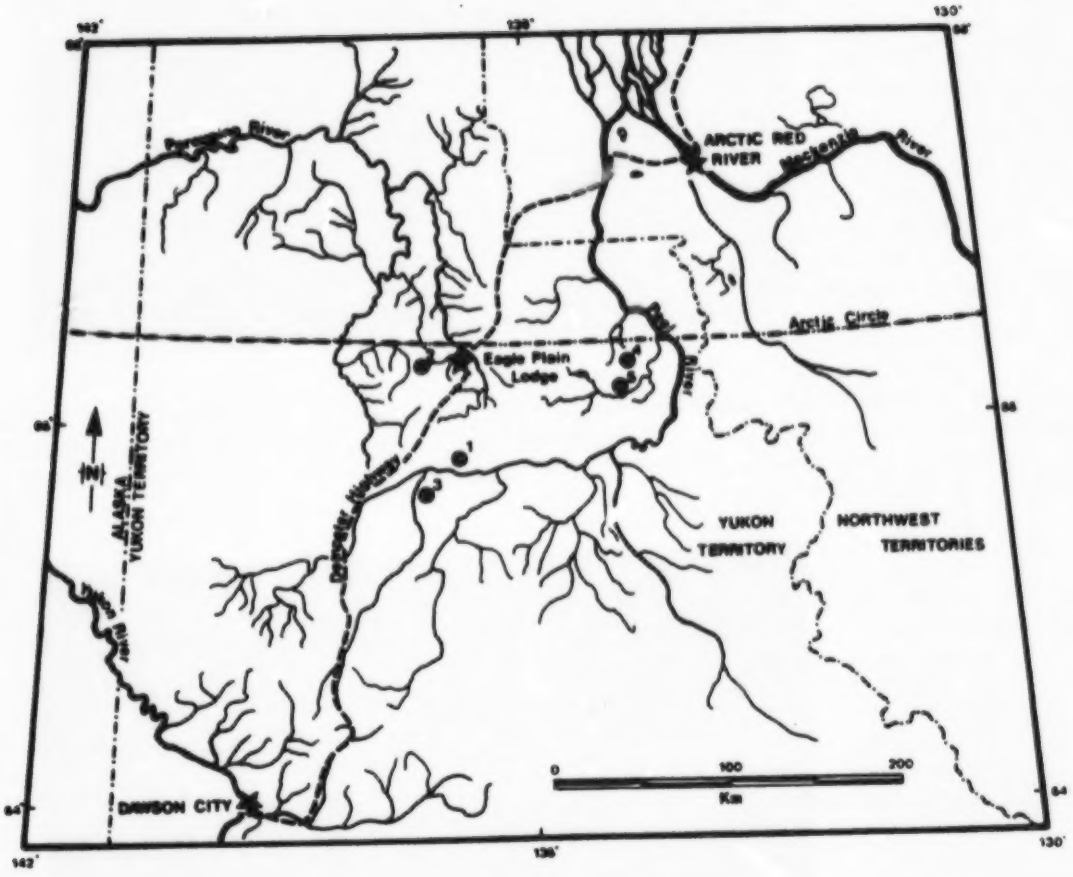
4.1. Aquitaine Alder C-33 (65°52'N; 136°54'W): NTS 116H

This wellsite was located on a relatively well drained, south facing, gently sloping (2 - 5°) interfluve, several kilometres south of the main Eagle Plain escarpment (Figure 13). The well, drilled during the winter of 1977-78, represents one of the most recent operations on Eagle Plain. Site rehabilitation was accomplished the following winter and final clean-up of the site took place in early July 1979 (Figure 14).

A gravel pad, composed of crushed sandstone obtained from the Eagle Plain escarpment, had been constructed during the 1976-1977 winter. The borrow pit was subsequently used as a drilling waste sump. The operation was atypical, therefore, since the main rig sump was not at the site itself.

4.1.1. Site conditions

From a terrain viewpoint, the Alder wellsite appears reasonably typical of conditions on Eagle Plain. Vegetation in the area consists of an open canopy of black spruce (*Picea mariana*) together with a shrub layer of birch (*Betula glandulosa*), alder (*Alnus sp.*) and some Labrador tea. A moss-lichen layer constitutes a surface organic mat exceeding 10 cm in thickness. At the wellsite the presence of white spruce (*Picea glauca*) and charred remnants of black spruce indicate a previous burn, the extent of which can be identified easily both in the field and from air photographs. In the non-burn area the black spruce average 5 - 6 m in height while in the burn area the white spruce are rarely more than 3 - 4 m in height. Tree ring counts suggest that the trees outside of the burn are 130 - 150 years old while those in the burn are between 40 - 70 years old. These data are consistent with our understanding of the role of fire in the boreal forest ecosystem (e.g. Rowe *et al.*,



1. Aquitaine Alder C-33
2. Chevron SOBC WM N.Parkin D-61
3. SOBC Blackstone D-77
4. Mobil Gulf Peel H-71
5. Gulf Mobil Caribou N-25

Figure 12. Location of the wellsites discussed in this report.

Figure 13. Oblique air view of the Aquitaine Alder C-33 wellsite prior to drilling in June 1977. The extent of the burn area is clearly visible. Lat. 65°52'N, Long. 136°54'W.

Figure 14. Oblique air view of the Aquitaine Alder C-33 wellsite, following site abandonment and rehabilitation, July 1979. The pad consisted of crushed bedrock (sandstone) obtained from the area.

1975; Wein et al., 1975; Zoltai and Pettapiece, 1973, 15-17). Indicators of patterned ground and solifluction are absent from the site although large hummocks, approximately 1 m in diameter and up to 15 - 30 cm in height, occur widely, similar to those described by Zoltai and Pettapiece (1973, 18-20). The 'drunken' appearance of the boreal forest, typical of ice-rich frost-susceptible soils in the Mackenzie Valley (e.g. Zoltai, 1975), is noticeably absent from Eagle Plain.

During early June 1977 geotechnical and terrain investigations were undertaken at the proposed wellsite location. The depth of the frost table and active layer temperatures were measured at several sites (Table 1). As to be expected, thaw depths bear a close relationship to vegetation cover and type. In general, the frost table was 12 - 13 cm deep beneath moss, 15 cm deep beneath Labrador tea, and 18 - 20 cm deep beneath lichen. By contrast, thaw depths were greater along a seismic line, where the tree canopy had been removed, ranging from 18 to 24 cm. These observations confirm the important thermal role which is played by vegetation in these northern boreal forest-shrub tundra environments.

Subsurface information is available from a number of shallow holes drilled by Mobile Augers Limited, of Edmonton. A lightweight, helicopter-transportable drilling rig was used. Several cores obtained from the proposed wellsite revealed 10 - 24 cm of organic material overlying approximately 2 - 4 m of reddish grey silty colluvium (Figure 15) which graded into highly weathered and fissile shale bedrock. Ground ice amounts were found to decrease with increasing depth (Table 2). Excess ice values of between 10 - 25% and natural water (ice) contents of between 18 - 30% were typical of the upper 2 m of permafrost. If one assumes liquid limit values of approximately 25 - 40% as being typical of silty colluvium, it follows that there is a high probability that the water (i.e. ice) content of these surficial sediments in their frozen state may exceed the liquid limit if they are allowed to thaw. This potential instability should not be over-emphasised however, since deeper cores retrieved from the underlying shale and sandstone bedrock indicated low ground ice amounts and high structural cohesiveness of the rock.

4.1.2. Terrain disturbances

The wellsite was drilled from a large gravel pad. The aggregate was obtained by the crushing of sandstone obtained from the main Eagle Plain escarpment to the north (Figure 3). A small sump was used during drilling but the majority of the waste fluids were transported to this borrow area and then buried. During the summer, operations at the site were terminated. As a result of these procedures, terrain disturbance adjacent to the rigpad was minimal

	SITE 1 Seismic Line	SITE 2 Spruce forest; burn area	SITE 3 Spruce forest; burn area
Depth:			
Surface	15.0°C	13.0°C	15.0°C
10 cm	11.0°C	6.0°C	12.0°C
20 cm	2.0°C	-	-
Frost table, cm. 9.6.1977	24.0	13.0	20.0
Vegetation:	Spagnum Lichen	Spruce Spagnum Lichen	Spruce Labrador tea Lichen Cranberry
Micro-relief:	Flat	Depression	Hummocky
Organic Mat, cm:	14.0	12.0	15.0

Table 1. Active layer conditions at the Aquitaine Alder C-33 wellsite, Eagle Plain, June 9, 1977 (from French, 1977).

Sample	Depth (cm)	Materials	Ice type*	Excess ice* (%)	Natural Water Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Range (%)
1	55-60	Colluvium	Vs, Vx	15-20	30.5	35.7	30.5	5.2
2	100-115	Colluvium	Vs, Vx	25	18.9	31.4	18.9	12.5
3	150-160	Colluvium	Vs, Vx, Vc	10-15	18.8	23.8	18.8	5.0
4	280-300	Weathered shale	Vc, Vx	0-5	6.2	20.8	6.2	14.6

*As defined by Pihlainen and Johnston, 1963.

Table 2. Ground ice amounts and consistency limits for surficial materials at the Aquitaine Alder C-33 wellsite, Eagle Plain (from French, 1977).

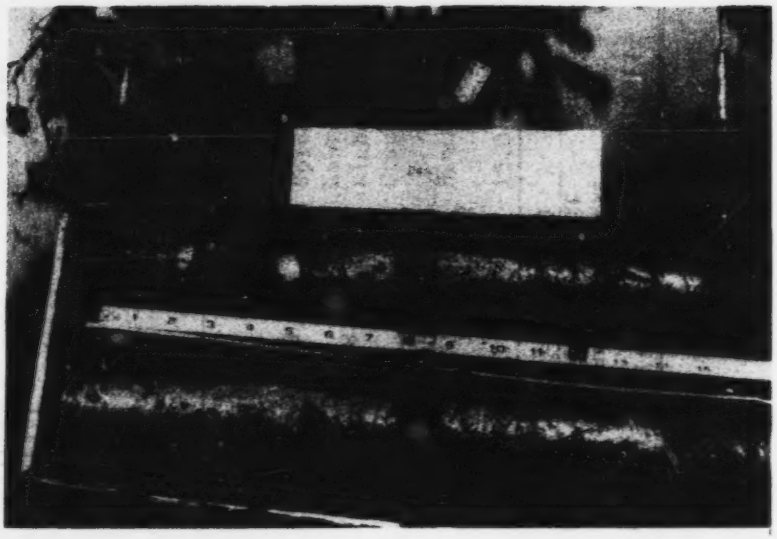


Figure 15. Drillcore of silty colluvium obtained from the upper 2 - 4 m of regolith at the Aquitaine Alder C-33 wellsite, Eagle Plain, June 1977. Note the ice lenses.

Figure 16. Oblique air view of borrow pit area for Aquitaine Alder C-33 wellsite, Eagle Plain, following site rehabilitation. Areas stripped of soil and vegetation show melt-out along joint patterns in underlying bedrock. The infilled borrow pits are to the left of the photo and elongate in plan. Photo taken - July 1979.

(Figure 14). Moreover, no signs of thawing of the permafrost, as might be indicated by slumping of the pad, were visible in July 1979. It was concluded that the methods adopted to prevent thaw were sufficiently effective to offset any increase in thaw consequent upon the removal of the trees and the surface vegetation layer.

The borrow pit from which the crushed bedrock aggregate was obtained was aligned along the crest of the Eagle Plain escarpment. When examined in July 1979, a rectangular network of linear depressions had formed in those areas where only the surface soil and vegetation had been removed (Figure 16). Undoubtedly, these linear depressions reflect the melt-out of ice from expanded joints in the underlying bedrock. As such, they are similar to the phenomena observed in the Dempster Highway borrow pits (Figure 11). Where actual quarrying and subsequent infilling had occurred, there were no signs of either slumping of the overburden or escape of buried waste drilling fluids.

Active layer temperatures measured in the stripped borrow pit areas were significantly higher than those measured in adjacent undisturbed terrain along the ridge crest (Table 3). Similarly, as might be expected, temperatures in the rigpad itself were considerably greater than those in adjacent vegetated areas. These observations highlight the high thermal conductivity of bedrock and the relatively deep thaw depths which can occur wherever bedrock is exposed. They also indicate that the 10' (3.04 m) thickness of the gravel pad recommended by the engineering consultants (EBA Engineering Consultants Ltd.) was appropriate.

Numerical simulation of bedrock thermal regimes in Eagle Plain has been undertaken by Pollard (1980) using a modified form of the MICRO model (Smith, 1977). Figure 17 displays the predicted thermal regimes for horizontal limestone and sandstone surfaces at 66°N, using climatic data from Dawson City, thereby approximating the southern part of Eagle Plain. The model predicts the occurrence of permafrost with a maximum depth of seasonal thaw of 3.3 m (limestone) and 3.0 m (sandstone). The slight difference between the two lithologies probably reflects the higher porosity values for sandstone used in the prediction, since these determine the latent heat terms. On Devon Island in the High Arctic (latitude 75°N), Brown (1973) observed active layer depths to 2.2 m in bedrock. Thus, the predictions for Eagle Plain are reasonable, and explain the exceptionally high temperatures encountered in bedrock terrain following disturbance. The absence of substantial thermokarst activity reflects (a) the low ice contents and, (b) the consolidated nature of the underlying bedrock.

Site		A.	B.	C.	D.
Material		Sandstone	Sandstone	Crushed sandstone aggregate	Silty colluvium (2-4 m) overlying shale bedrock
Vegetation		Birch, poplar, white spruce, moss-lichen	Stripped of soil and vegetation	-	White spruce, moss-lichen
Depth: (cm)	Surface	17.5°C	17.5°C	18.0°C	20.0°C
	10	6.0°C	18.0°C	17.5°C	7.5°C
	20	5.0°C	18.0°C	17.0°C	-
	30	-	19.0°C	-	-
	40	-	19.0°C	17.0°C	2.0°C
	50	3.0°C	-	-	-
Frost Table:		n.d.	n.d.	n.d.	n.d.

Table 3. Active layer temperatures (°C) measured at the Aquitaine Alder C-33 wellsite, July 27, 1979. (A) Undisturbed bedrock terrain, Eagle Plain escarpment. (B) Stripped bedrock, Eagle Plain escarpment. (C) Drilling pad composed of crushed bedrock aggregate. (D) Undisturbed terrain adjacent to wellsite. Note the similarities in thermal regimes between (A) and (D) and between (B) and (C).

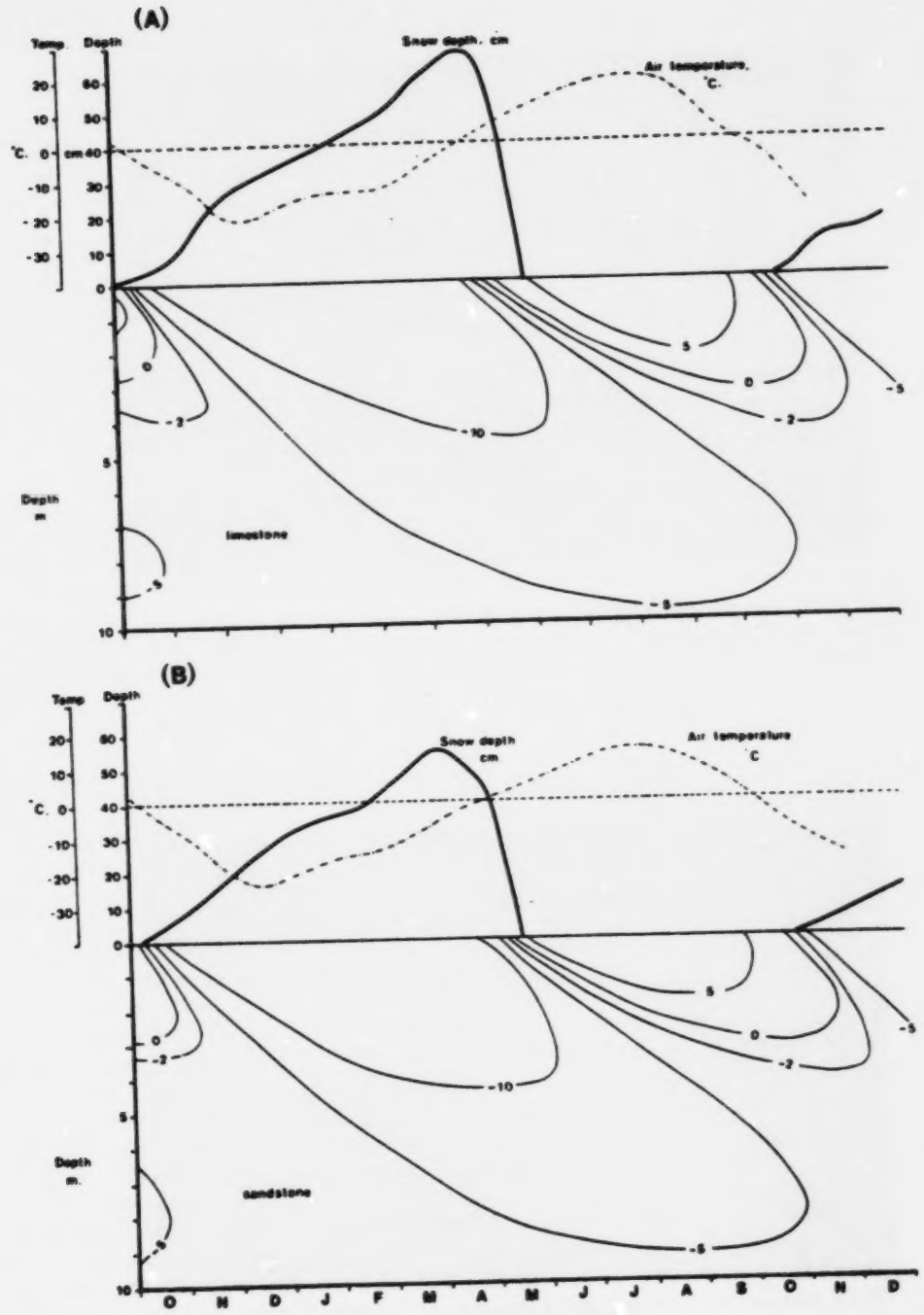


Figure 17. Predicted thermal regimes for horizontal limestone (A) and sandstone (B) surfaces in the Eagle Plain. From Pollard, 1980, 27.

4.2. Chevron SOBC WM N. Parkin D-61 (66°20'N; 137°13'W); NTS 116I

This well, drilled during the 1971-72 winter, was one of the first to be drilled in winter on the upland surface of Eagle Plain following the introduction of the Territorial Land Use Regulations. Many of the terrain conditions discussed with respect to the Aquitaine Alder C-33 wellsite are applicable to this site.

In general, minimal terrain disturbance was observed (Figure 18), reflecting the one-season, winter drilling program and the low terrain sensitivity of the site. A revegetation program had been undertaken and there were few signs of obvious vehicle rutting around the site. The limited nature of thermokarst activity on the upland surfaces of Eagle Plain was seen at the nearby Hercules airstrip. As at the Aquitaine Alder C-33 borrow pit, the stripped shoulder was characterised only by a rectangular pattern of thawed expanded joints.

In summary, this site represented a well timed and executed winter operation in a relatively well drained area underlain by consolidated bedrock possessing low ground ice amounts. The absence of a rigpad probably reflected the absence of easily accessible surficial aggregate and the desire, by the land use regulatory bodies at that time, not to excavate borrow pits in the bedrock. In retrospect, it may be concluded that such a pad was unnecessary in any case.

4.3. SOBC Blackstone D-77 (65°40'N; 137°15'W): NTS 116H

Two factors make the Blackstone D-77 wellsite of particular interest in any assessment of wellsite disturbances in the interior Yukon Territory.

First, in contrast to the majority of wells drilled on Eagle Plain, this well was located on gently sloping terrain occurring towards the bottom of a south-north trending tributary valley of Blackstone River. Poor drainage conditions together with silty ice-rich colluvial sediments produce an open forest woodland of black spruce (*Picea mariana*) and tamarack (*Larix sp.*) with a relatively dense shrub layer (shrub birch, willow, ericaceous shrubs) and sedges (*Carex spp.*). In these moister environments of the interior Yukon, a slightly different fire cycle occurs to that characteristic of well drained sites. According to Zoltai and Pettapiece (1973, 16), in moist environments, sedge and cottongrass tussocks survive the fire and thrive in the absence of competition and because of the increased moisture associated with the thickening of the active layer. This makes the re-establishment of black spruce and tamarack difficult. The result is the development of areas of fire-induced tundra composed of tussocks or tussock-dwarf birch. The same sequence of

Figure 18. Oblique air view of the Chevron SOBC WM N. Parkin D-61 wellsite, located on the upland surface of Eagle Plain. Photo taken - July 1979.

Figure 19. Remnants of old pile-supported rigpad are still visible at the SOBC Blackstone D-77 wellsite, drilled in 1962-63. Photo taken - July 1979.

vegetation changes should be expected following wellsite disturbances in these areas.

Second, the well was drilled prior to the introduction of the Territorial Land Use Regulations. It was a two season operation which commenced in March 1962 and finished in January 1963. In all probability, there was activity around the site during the summer of 1962 but the nature of this activity is difficult to ascertain from the well records. It would appear that the well was drilled from a pile-supported platform, remnants of which still exist at the site (Figure 19).

As a result of these operating procedures, it is not surprising that substantial thermokarst developed within the area of the well-site. Thermokarst mounds, 1 - 3 m in height together with deep pools of standing water, 2 - 4 m deep in places, surround the old drilling platform (Figure 20). Thaw depths in the disturbed terrain commonly exceed 90 cm while those in adjacent undisturbed terrain are less than 45 cm. Revegetation, in the form of sedges, mosses, shrub birch, and cottongrass, has occurred naturally and this has helped stabilise the terrain. Also the presence of fescue and timothy grasses suggest artificial revegetation at some time in the past.

Seismic lines had been shot in summer. In the vicinity of the wellsite they reveal a similar history of physical disturbance and thermokarst (Figure 21). The removal of trees and surface organic material led to the formation of water-filled trenches, 80 - 100 cm deep, colonised by aquatic plants (Equisetum sp., carex sp., mosses). Ramparts on either side of the trench reflect the bulldozed and re-deposited surface materials.

In summary, the SOBC Blackstone D-77 wellsite is a sensitive one. It illustrates some inadequacies of industry operational procedures prior to the introduction of the Territorial Land Use Regulations. The thermokarst topography which has resulted is similar to that described elsewhere from the boreal forest and forest-tundra zones of North America (e.g. Péwé, 1954; Kerfoot, 1974) and the Soviet Union (e.g. French, 1975, 139-43).

4.4. Mobil Gulf Peel H-71 (66°20'N; 134°43'W): NTS 106L

Interest in this wellsite arose from reports which indicated that a second sump had been constructed to contain waste fluids and that physical disturbance had occurred at the adjacent Hercules airstrip. The conditions which led to the construction of the second sump are not known and can only be speculated. An inadequate sized initial sump or downhole problems leading to excessive waste fluid production are likely explanations. The well was drilled during the summer of 1977 and site rehabilitation was accomplished in the spring of 1978.

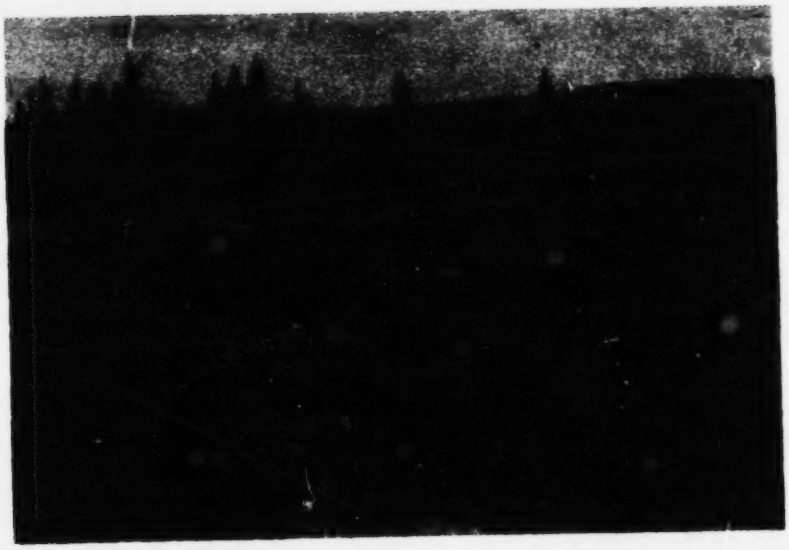


Figure 20. Thermokarst mounds and pools of standing water have formed in the disturbed terrain adjacent to the SOBC Blackstone D-77 wellsite. Photo taken - July 1979.

Figure 21. Oblique air view of old seismic line traversing poorly drained ice-rich terrain, Blackstone River Valley. The seismic line was shot in summer. Note the thermokarst which has occurred. Vegetation is a fire-induced shrub tundra and tussock tundra. Lat. 65°45'N, Long. 137°15'W.

The wellsite is located on the flat upland surface of the Peel Plateau. Vegetation in the area consists of an open woodland of black (Picea mariana) and white spruce (Picea glauca) together with extensive areas of shrub tundra. Where valleys dissect the plateau white birch (Betula papyrifera) occurs on well drained southwest-facing slopes and stunted black spruce on northeast-facing slopes. Peat plateaus, areas of peat polygons and wet fenlands are also present. The underlying bedrock is rarely exposed since a silty clayey till veneers the surface. Areas of ice-rich lacustrine sediments are indicated by shallow depressions containing numerous small thaw lakes. A number of active and inactive flow slides provide further evidence of the ice-rich nature of the surficial materials. These are particularly common in recent burn areas (e.g. Zoltai and Pettapiece, 1973, Figure 15).

Terrain disturbance around the wellsite is not extensive (Figure 22) and undoubtedly reflects the strict application of land use procedures during the critical summer thaw period. The potential for vehicle rutting is illustrated by several deep tracks made during the final stages of site rehabilitation, probably in the early spring of 1978. The auxiliary sump is located on slightly lower ground adjacent to the main sump and near a shallow drainage line. Both sumps show signs of poor infilling. Escape of toxic fluids from the downslope end of the auxiliary sump is indicated by a swath of dead or dying spruce trees (Figure 22), the extent of which follows the small drainage depression for approximately 150 m. The cause of this fluid escape can only be speculative. One possibility is that 4.0' (1.3 m) of freeboard, as specified in the permit conditions, had not been maintained and seepage subsequently occurred along the top of the permafrost table. Since there is no mention of this in the various land use inspection reports, another possibility relates to the melt-out of ice contained within the silty clay used to construct a small retaining dyke at the lower end of the sump. This mechanism appears to be a common cause of seepage of sump fluids during summer wherever retaining dykes are constructed using ice-rich and fine grained sediments (e.g. Gulf Parsons Lake N-10, French, 1978; Gulf Caribou N-25, see below).

The winter airstrip had been located deliberately in an area of peat polygons and shrub tundra vegetation (Figure 23). As a result, relatively few trees had been removed. Field inspection revealed physical damage restricted to surface scuffing of small incipient peat plateaus (Figure 5) and serious terrain problems were not recognised.

Figure 22. Air view of the Mobil Gulf Peel H-71 wellsite showing auxiliary sump and adjacent area of dead trees. Photo taken - July 1979.

Figure 23. Oblique air view of peat polygon and wet fenland terrain, Peel Plateau. This site was used as a winter airstrip for the Mobil Gulf Peel H-71 wellsite in the 1976-77 winter. Lat. 66°21'N, Long.134°45'W. Photo taken - July 1979.

4.5. Gulf Mobil Caribou N-25 (66°14'N; 134°50'W): NTS 106L

Land use records indicate that this wellsite experienced severe terrain problems associated with the escape of waste drilling fluids. The well was drilled during the summer of 1974. The present investigation sought to identify the local terrain and geomorphic factors involved, in the hope that their recognition might prevent the occurrence of similar problems elsewhere in the future.

The condition of the site when visited in July 1979 is illustrated in Figure 24. A sizeable area downslope from the sump had experienced substantial gullying, mudflows, and slumping.

Central to the problems encountered at this wellsite is its location. This is upon a narrow interfluve separating two deeply incised tributary valleys of the Caribou River. In this part of Peel Plateau the flanks of the upland surface are drained by several small streams. These give rise to locally extensive areas of highly dissected terrain mantled with reworked glacial sediments. These are commonly fine grained (>40% clay content) and possess high ice contents. IAND Land Use Inspector reports indicate that the sump was excavated almost entirely in such materials and that ice lenses were exposed in the sump walls. Since the interfluve was narrow, the sump, of necessity, was constructed close to the western edge of the interfluve. As a result, a large containment dyke had to be constructed. Material excavated from the sump was used for this purpose. Given its southwesterly exposure and its lack of insulation, it is perhaps not surprising that the dyke thawed in late summer and slumping occurred leading to the escape of fluids through the dyke (Figure 25). The following summer, after site rehabilitation that winter, further slumping and mass wasting occurred at the site of the leakage (Figure 26). Clearly, the sump fluids had not frozen *in situ* in the permafrost and the weight of the sump overburden led to the seepage which triggered the renewed slumping. In addition, instability was accentuated by the freezing and expansion forces of waste fluids with depressed freezing temperatures. By 1979, a revegetation program had met with some success (Figure 27).

In retrospect, the factors contributing to these terrain problems can be summarised as follows:

(i) The geographic location of the wellsite necessitated sump construction on a steep slope, prone to gravity-induced mass wasting processes.

(ii) The ice-rich and fine-grained nature of the sump infill materials which were used to construct the retaining dyke favoured thawing and instability.

Figure 24. Oblique air view of the Gulf Mobil Caribou N-25 wellsite, Peel Plateau, showing extent of slumping and of western side of the sump. Photo taken - July 1979.

Figure 25. Gulf Mobil Caribou N-25 wellsite, September 1974, showing leakage of fluids through sump wall. Note how close the sump was located to the edge of the valley slope. Photo: Courtesy of W. Robson, Fisheries and Environment Canada, Whitehorse.

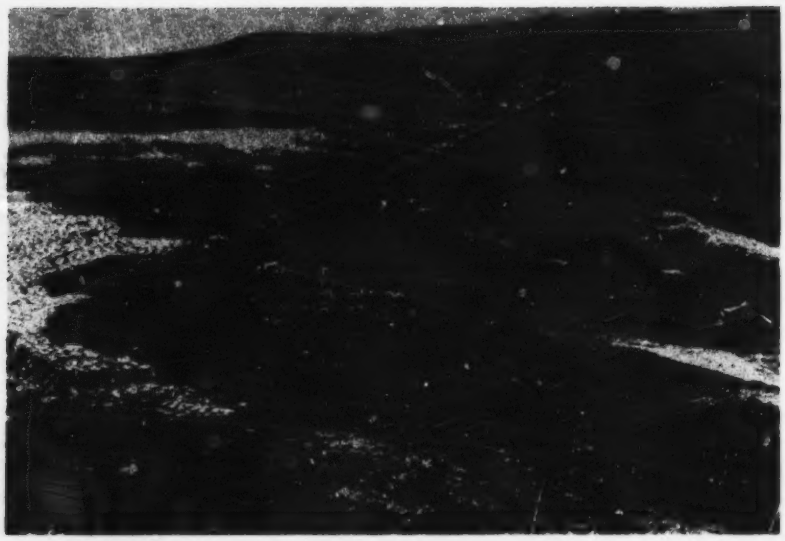


Figure 26. Gulf Mobil Caribou N-25 wellsite, September 1975, following site rehabilitation. Slumping and mass wasting occurred at the site of the initial leak of sump fluids. Photo: Courtesy of W. Robson, Fisheries and Environment Canada, Whitehorse.

Figure 27. Gulf Mobil Caribou N-25 wellsite, July 1979, showing slope stabilisation and revegetation. Seepage from the disturbed area is still occurring. Compare with Figure 26.

(iii) The drilling operation was carried out entirely in summer and, as a consequence, the waste drilling fluids did not freeze completely prior to site rehabilitation the following winter.

(iv) Measures to prevent thaw of the sump walls during summer were not undertaken.

The toxic and biological aspects of the escape of waste fluids at this site are being documented by Smith and James (1981, in preparation). From the geomorphological viewpoint, the relative success of the revegetation program needs to be highlighted. Although the re-establishment of the original spruce cover may take several hundred years (Zoltai and Pettapiece, 1973, 16), the terrain stabilization which has occurred contrasts with tundra and polar desert environments where similar cases of terrain instability would probably promote self-generating ground ice slumps and multiple retrogressive thaw-flow slides. Unfortunately, there is a lack of long term studies of mass wasting in the interior northern Yukon to enable quantification of these differences.

5. DISCUSSIONS AND CONCLUSIONS

The localities described in this report were selected either because of known terrain and sump-related problems, or because they are thought representative of wellsite disturbances in general in northern interior Yukon Territory. Table 4 summarises information concerning the five wellsites. Early, pre-land use operations are illustrated by the SOBC Blackstone D-77 wellsite. The other drilling operations were all under land use permits. Localities of high and low terrain sensitivity are illustrated by this and the Chevron SOBC WM N. Parkin D-61 wellsites respectively. The Gulf Mobil Caribou N-25 wellsite appears atypical and is best interpreted within the context of local site specific conditions.

Bearing these constraints in mind, a general conclusion is that sump-related problems in interior Yukon Territory are not as obvious or as common as in parts of the Northwest Territories, notably the Mackenzie Delta and the Arctic Islands. This is particularly true for Eagle Plain, less so for Peel Plateau.

Several factors are involved in this assessment. First, the general terrain sensitivity of much of interior Yukon is lower than in areas such as the Mackenzie Delta. This is because of the absence of unconsolidated ice-rich surficial materials from the unglaciated areas (e.g. Eagle Plain) and instead, the widespread occurrence of well drained coherent bedrock surfaces of generally low ice content. The higher terrain sensitivity of Peel Plateau appears to be a combination of (a) the presence of ice-rich and fine grained glacial and lacustrine sediments and (b) the highly dissected nature of certain areas. Second, the revegetation and stabilisation of disturbed areas in the boreal forest and shrub tundra environments of interior Yukon occurs relatively quickly when compared to further north. Observations from the Blackstone wellsite suggest that natural recolonisation, similar to the changes following fire, is as successful as artificial seeding over the long term (i.e. 15 - 25 years). However, the Caribou revegetation program also illustrates the applicability of immediate, short term artificial revegetation. If the goal of site rehabilitation measures is to restore the ground as closely as possible to its undisturbed state, trade-offs with respect to procedures must be recognised. For example, if a gravel pad is the best ground protection, then it may be preferable to 'sacrifice' a small area as a borrow pit, and to concentrate revegetation programs at that locality when the operation is finished.

The role of the Territorial Land Use Regulations in minimising terrain disturbances in the Yukon Territory must also be emphasised. The early Blackstone wellsite illustrates how, in highly sensitive

Wellsite	Location	Surficial Materials or Bedrock	Start and Completion Dates*	Terminal Depths* (m)	Nature of Drilling Operation	Terrain Disturbance Conditions and/or Sump-related Problems and/or General Comments
Aquitaine Alder C-33	Sloping terrain, Eagle Plain	3 m colluvium, ice-rich, overlying bedrock	08-03-78 04-03-79	3714	One season, winter operation	No terrain problems. No sump at site; use of borrow pit for waste fluid containment. Crushed sandstone used for rigpad. Pre-site investigations.
Chevron SOBC WM N. Parkin D-61	Upland surface, Eagle Plain	Sandstone bedrock	04-01-72 17-04-72	3352	One season, winter operation	No problems. No rigpad constructed.
SOBC Blackstone D-77	Valley bottom, poorly drained	Ice-rich colluvium	10-03-62 08-01-63	4028	Two season, summer operation	Terrain disturbance and thermokarst. Operation conducted prior to Territorial Land Use Regulations.
Mobil Gulf Peel H-71	Upland surface, Peel Plateau	Till	05-02-77 12-06-77	3392	Two season, summer operation	Auxiliary sump constructed. Fluid outflow and toxicity effects.
Gulf Mobil Caribou N-25	Narrow interfluve, Peel Plateau	Till	01-05-74 10-08-74	3600	One season, summer operation	Escape of fluids via melt-out of sump wall to adjacent stream. Erosion and slumping of sump in subsequent years.

*Source: Schedule of Wells 1920-1979, Northwest Territories and Yukon Territory. Northern Non-Renewable Resources Branch, Oil and Gas Resource Evaluation Division, Exploratory Operations Section, Indian and Northern Affairs, Ottawa. Catalogue No. R72-21/1979.

Table 4. Summary information concerning the wellsites described in this report.

locations, thermokarst may result which is similar to that which occurs in other sensitive northern environments. One must also recognise the greater site planning and cognizance of terrain problems by industry in recent years. The Aquitaine Alder C-33 operation, in which drilling took place upon a large gravel pad following detailed pre-site soil, permafrost and geotechnical investigation, is an example of modern and effective land use procedures.

With the exception of the Mobil Gulf Peel H-71 wellsite, the escape of drilling fluids does not appear to have caused obvious toxicity effects, although one must await the results of biological investigations to be certain of this. Instead, field observations described in this report suggest that physical disturbances are more important. This is not to imply that the loss of trees and other biomass is unimportant. The significance of such changes clearly depends on scale and cumulative effects, plus the relative values placed on the various components of the vegetation assemblage from resource, habitat, and ecology viewpoints. In summer-sensitive locations where the potential for severe terrain disturbance exists (e.g. SOBC Blackstone D-77 and Gulf Mobil Caribou N-25) consideration ought to be given to either surface disposal of fluids or their trucking to official disposal sites.

Table 4 also illustrates the importance of the timing of the well drilling operation. Wells drilled either in summer or extended into the summer period appear to have a high probability of experiencing terrain and/or drilling fluid containment problems whereas one season winter drilling operations apparently create few problems. Moreover, the relative 'sophistication' of the Aquitaine Alder C-33 operation, where an innovative waste disposal program was undertaken, can be contrasted with the earlier Chevron SOBC WN N. Parkin D-61 operation, where simple application of land use regulations at a low sensitivity site drilled in winter ensured equally minimal impact. As such, these two wellsites can be used to illustrate not only the progressive evolution in the application and efficacy of the Territorial Land Use Regulations on Eagle Plain but also the variations in wellsite conditions and associated operating procedures required of the permittee.

6. RECOMMENDATIONS

1. In areas such as Eagle Plain, crushed bedrock should be used as aggregate for the rigpad and the borrow pit, so created, used to contain waste drilling fluids. This procedure is applicable to both summer and winter operations.

2. The use of below-ground sumps for the containment of waste drilling fluids appears to work satisfactorily in many wells drilled in winter in the northern Yukon Territory. However, consideration should be given to the surface disposal of fluids, if non-toxic, in certain locations, especially if the well is to be drilled in summer.

3. In glaciated areas such as Peel Plateau, where clayey till and ice-rich lacustrine sediments are widespread, every effort should be made to conduct drilling operations during the winter months. Also, if the waste fluids are non-toxic, surface disposal should be considered.

4. In topographic situations where a sump is used, and where the possibility of fluid escape is high on account of the use of retaining dykes, drilling ought to be restricted to one season winter operations, thereby ensuring the freezing of waste drilling fluids.

5. Air photo interpretation and site investigations prior to the granting of the Land Use Permit can help to prevent or minimise terrain disturbance problems. These procedures should be undertaken during the summer months when the absence of snow enables soil and vegetation conditions, in particular, to be better assessed. Geotechnical investigations which may require heavy equipment (e.g. surficial drilling) might be recommended in winter in those localities where summer movement is difficult or likely to cause damage.

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